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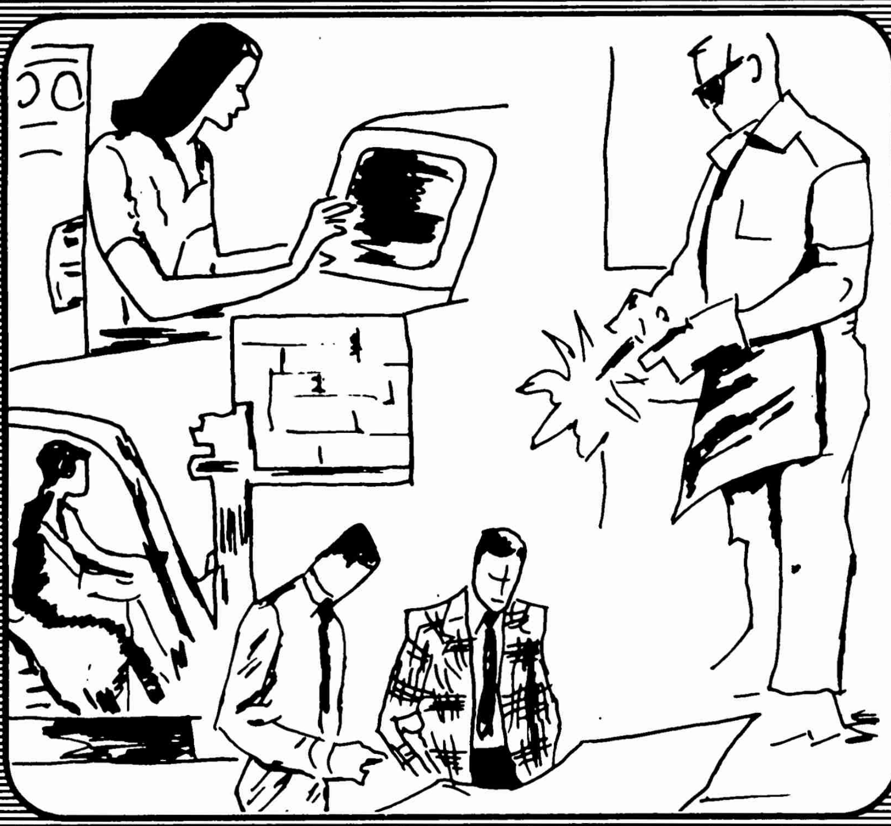
OCMM RESEARCH REPORT NO. 18

A COMPUTER SUPPORT SYSTEM FOR LARGE-SCALE MANPOWER PLANNING

BY R.J. NIEHAUS
D. SHOLTZ



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ABSTRACT

This paper discusses the computer software system for manpower planning developed by the Navy Department's Office of Civilian Manpower Management. First, the problem is discussed, followed by a description of the formulation of the model for recruiting requirements planning. Then, a description of the system flow is given, starting with the sources of input data, moving to the various intermediate processing subsystems, and closing with the model matrix generator and output processing. Examples of the various system outputs and underlying model structures are given. The final section of the paper describes various operational and research applications which have been completed or which are contemplated.

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Office of Civilian Manpower Management
Navy Department
Washington, D. C. 20390

INTRODUCTION

This paper discusses models developed by the Navy Department's Office of Civilian Manpower Management. OCMM, as it is usually called, is responsible for developing, directing, and appraising programs and activities which will ensure a civilian staff of appropriate quality and quantity for the Navy Department -- a workforce now numbering in excess of 300,000 employees worldwide. Our branch, in particular, has been involved for the past six years in research on mathematical computer-assisted models in several areas of manpower management.1/ It is with using linear programming in the models in one of these areas, that of forecasting recruiting requirements, that this paper is concerned.

STATEMENT OF PROBLEM

The problem we addressed is as follows: given a knowledge of (or a guess at) the numbers of people, by occupational specialty and level, needed at certain times in the future, to determine the numbers and kinds of employees who ought to be hired (or fired) at each time. At first glance this seems a modest enough problem; a little thought will show, though, that many advantages are to be gained through the application of a computerized model. For one thing, if a future cut seems likely, it may be better not to hire everyone possible now if you're only going to have to fire later; it may be better to use the money for something else -- like substituting technology for manpower. Again, the sheer amount of data and the number of constraints that are relevant is more than any one man can reasonably deal with.

1/ See bibliography.

First, of course, we need estimates by occupational specialty and level of total numbers of employees needed at each time; these are our goals. Then, the manager must operate within certain constraints, one of which is the ceiling -- an arbitrary fixed total number of employees set in the budgetary process. Another constraint is the budget; and in order to work with a manpower budget, you have to know salaries. So far, there is nothing surprising, or that anyone would be likely to forget.

But another very important factor that is sometimes not taken completely into account is transition rates. Because you have a number of employees of a given kind now, does not mean that you can count on having them at a future time. Some will move to other occupations. More will be promoted. Still others will leave. And beyond that, let's say that a manager knows that he will need a given number of employees of a certain type four years from now; the best way of meeting this need may very well not be to wait until that time and then attempt to hire them, but rather to hire enough lower-level employees of that specialty now -- even though he may not need them now -- so that they will be at the appropriate level and have the necessary experience when they are needed.

Another kind of constraint is limits on the numbers of employees of any given kind. There may, for instance, be occupational specialties in which you must have certain minimum levels. In such cases you would want to impose lower limits on the numbers of people in these positions. Similarly, you may want to set maximum levels for some occupational specialties.

Finally, there must be some way of indicating preferences or priorities. To see what's involved here, let's look at an example. If, in a given year, you are going to end with a surplus of a certain type of worker, there are two things you can do; you can fire the excess, or you can simply decide to live with it. For any of a great reasons -- there are so few of these workers, they're so near retirement, the surplus is probably only temporary, etc., -- it may be better in the long run simply to keep the excess in this category rather than to fire people. And it's not necessary to go all one way or the other; there can be a continuum: up to a given point you can tolerate an excess, but beyond that, any surplus employees will have to go. Contrariwise, if you're going to have a shortage of a given type of worker, again there are two possibilities: either you can scrape up the money and make good the shortage, or you can live with the reduced level of workers here, and use the money in another area where the shortage may be even more critical.

These, then, are the basic types of data and constraints needed. We might now look at the problem of formulating a model from these data.

FORMULATION OF MODEL

The particular formulation used was developed by the authors of this paper together with Dr. A. Charnes of the University of Texas and Dean W. W. Cooper of Carnegie-Mellon University, and is of the goal-programming variety.2/ That is to say, here we do not try to maximize profit (there isn't any in the government) or minimize cost (also not possible in a program-oriented environment); instead, we try to minimize the weighted sum of discrepancies

2/ See Parts I and II of [4].

from a set of goals. This model is transformed into a linear program for solution purposes. Then all the capabilities of a third generation linear programming language such as the UNIVAC Functional Mathematical Programming System (FMPS) can be used.

Let's look first at the variables for which we want to solve, and which will therefore be the columns of our Linear Programming (LP) matrix. We have first, for each period, the number of employees aboard, by occupational specialty and level. Next, we have, again by period, the numbers of hires and of fires. The other variable we have is the discrepancy between the number aboard and the number desired, or the goal. In order to be able to work only with positive variables, we can split this discrepancy into excesses and deficiencies.

Now, we can begin to look at the various kinds of constraints, which will form the rows of our LP matrix. First, we can establish our starting population; the number onboard in each job category at the base time is equal to the initial population. Then we can define the discrepancies by a set of equations which say: the number of employees on board in each job category in each period (aboard) less any amount over (excess) plus any amount under (deficiency) equals the manpower requirements (goals).

Now, people are going to move from one job category to another during any period; if we multiply a matrix of expected transition rates by the numbers on board at any time, the resulting values will be the numbers remaining on board at the next time. If we then subtract these values from the totals

aboard at that time, subtract the numbers hired and add the numbers fired, the results will be zero. In other words, the numbers currently on board at any time are equal to (transposing) the numbers left from last time plus any new hires less any fires.

The preceding sets of constraints essentially define the variables, and thus, the problem. The remaining constraints merely impose limits on the possible solutions. First, if we sum the numbers on board in each category by period, those sums must not be greater than the imposed ceiling for each period. Similarly, if we sum for each time the products formed by multiplying the number on board in each category by the salary for that category, these sums must not exceed the manpower budget for each period. Finally, we can impose bounds on the numbers of employees in each job category at each time: the numbers must not be lower than the lower limits, nor exceed the upper limits.

That completes the body of the LP matrix. Now, normally there will be a great number of solutions which will meet all the criteria set forth. Of these we would like the one which will minimize the total discrepancy from our goals, as well as reflect the relative costs of hiring and firing. In this way, we can favor hires over deficiencies, and excesses over fires, for example. Thus, we assign a weight (or priority) to each of the hire, fire, excess, and deficiency variables, and ask for the solution which will minimize the sum of those products. A schematic representation of the resultant LP problem can be found in Figure 1.

ABOARD			HIRES		FIRES		EXCESSES		DEFICIENCIES			RHS
Base	Projected											
1											=	Init. Pop.
	1						-1		1		=	Goals
		1						-1		1		
-M	1		-1		1						=	0
	-M	1		-1		1						
	1...1										≤	Ceilings
		1...1										
	sal...sal										≤	Budgets
		sal...sal										
	1										≥	Lower Limits
		1										
	1										≤	Upper Limits
		1										
MINIMIZE			α		β		γ		δ			

RECRUITING REQUIREMENTS MODEL

Figure 1

SUPPORTING SYSTEM

To provide the input data for the LP solution of this model, we use a supporting computer system called the Computer-Assisted Manpower Analyses System (CAMAS).3/ Actually, that system existed in part long before we were ready to do any LP runs, and in fact produces a number of by-products which are highly useful in their own right.

We draw our information from two principal sources: data on the Navy's civilian personnel is drawn from the centralized personnel inventory system maintained by our office (OCMM); data on the Navy's future requirements is derived from the Department of Defense Five Year Defense Plan (usually referred to as the FYDP).

As can be seen in Figure 2, a Personnel Master File is created by combining the Personnel Inventory Files for two different points in time; this resulting file will be used both for calculating the rates of movement in the civilian workforce and to establish the current distribution of the population by job-type. The Activity Master File is created from a file maintained by OCMM and containing information on each of the 1,000 Naval activities around the world that employ civilians; to it is added the FYDP data which comes to us through the Navy's Office of the Comptroller. The resulting file is used not only in determining the personnel requirements for the future, but also in permitting the system to be run at any desired level, whether it be the Navy as a whole, individual activities, or some intermediate level such as geographical area or major claimant (the Navy's organizational subdivisions) or program element (financial subdivisions).

3/ See Chapter III of Part I of [4].

COMPUTER-ASSISTED MANPOWER ANALYSES SYSTEM (CAMAS)
PERSONNEL MASTER FILE

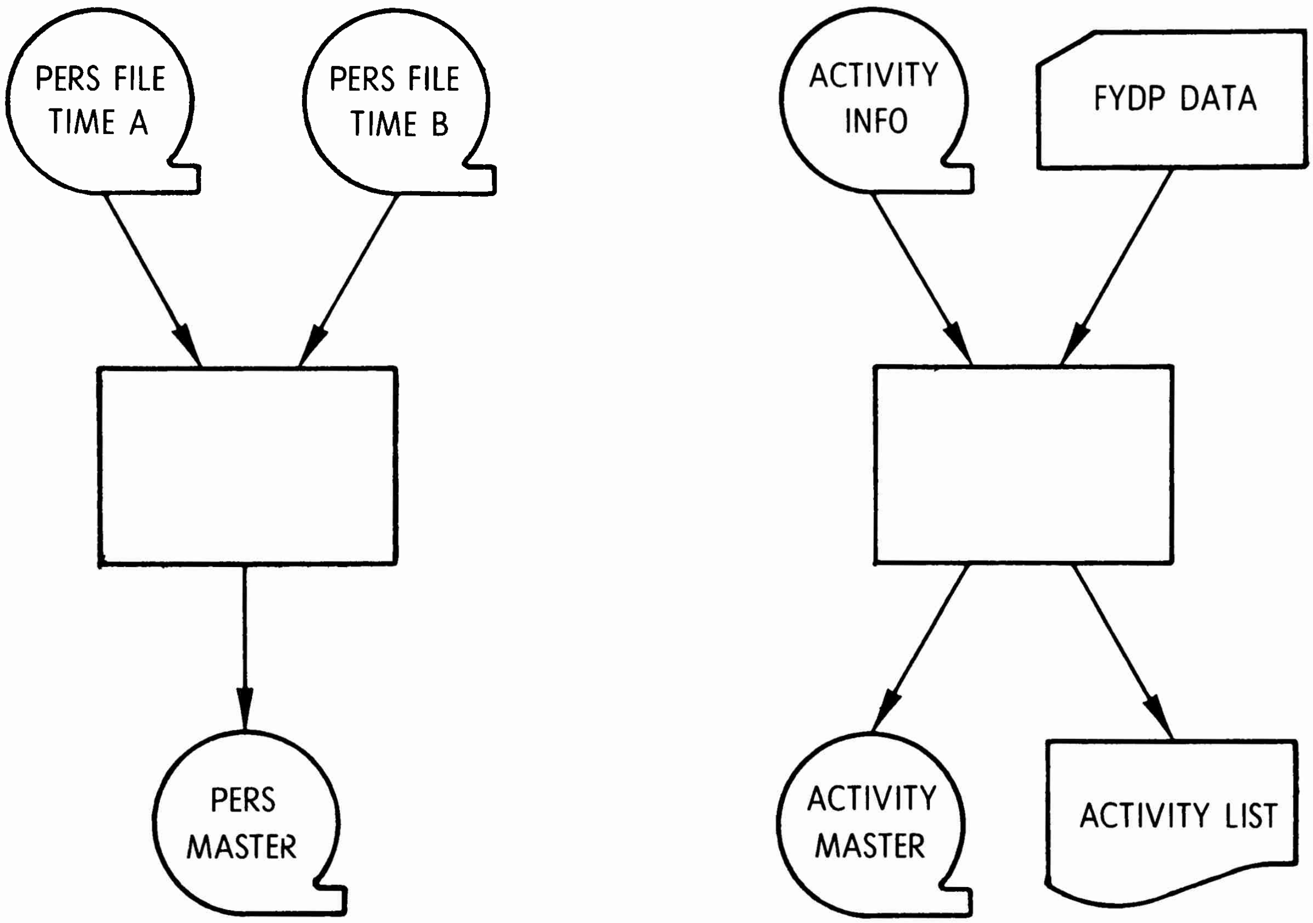

Figure 2

These are our master files. Figure 3 shows how the Personnel Master is broken into two parts: the projected retirements, and the basic population who are ineligible for retirement. The reason for explicitly addressing the question of retirement rates is the composition of the Navy civilian workforce. At the time of the Second World War a great number of employees were hired all within a relatively short period; as we now approach the time when most are becoming eligible to retire, we can not apply historical turnover rates to the population as a whole, but must take into account this large body of retirement eligibles. Thus, transition -- or turnover -- rates are calculated separately for the two segments of the population, and then recombined.

The subsystem for calculating these rates for the basic population can also be used to look at any sort of movement in the population -- occupational, promotional, geographic, organizational, etc. It can also be used to look at any subset of the population based on sex, age, length of service, minority membership, activity, organizational unit, geographical area, job type, level, or financial program, and thus it is highly useful in its own right. In fact, this subsystem was for a period of time the principal output for users, while we worked on the models which required a longer development time before being capable of providing useful results. A sample of a transition rate report is provided as Figure 4.

The projected retirements are aggregated and selected according to the selection criteria, and a report is produced by any desired grouping; the activity master is used here simply to translate codes into English language. A sample of this report is given in Figure 5. The activity master is then used in combination with the personnel master to calculate

COMPUTER ASSISTED MANPOWER ANALYSES SYSTEM (CAMAS)

GROSS REQUIREMENTS AND TRANSITION DATA

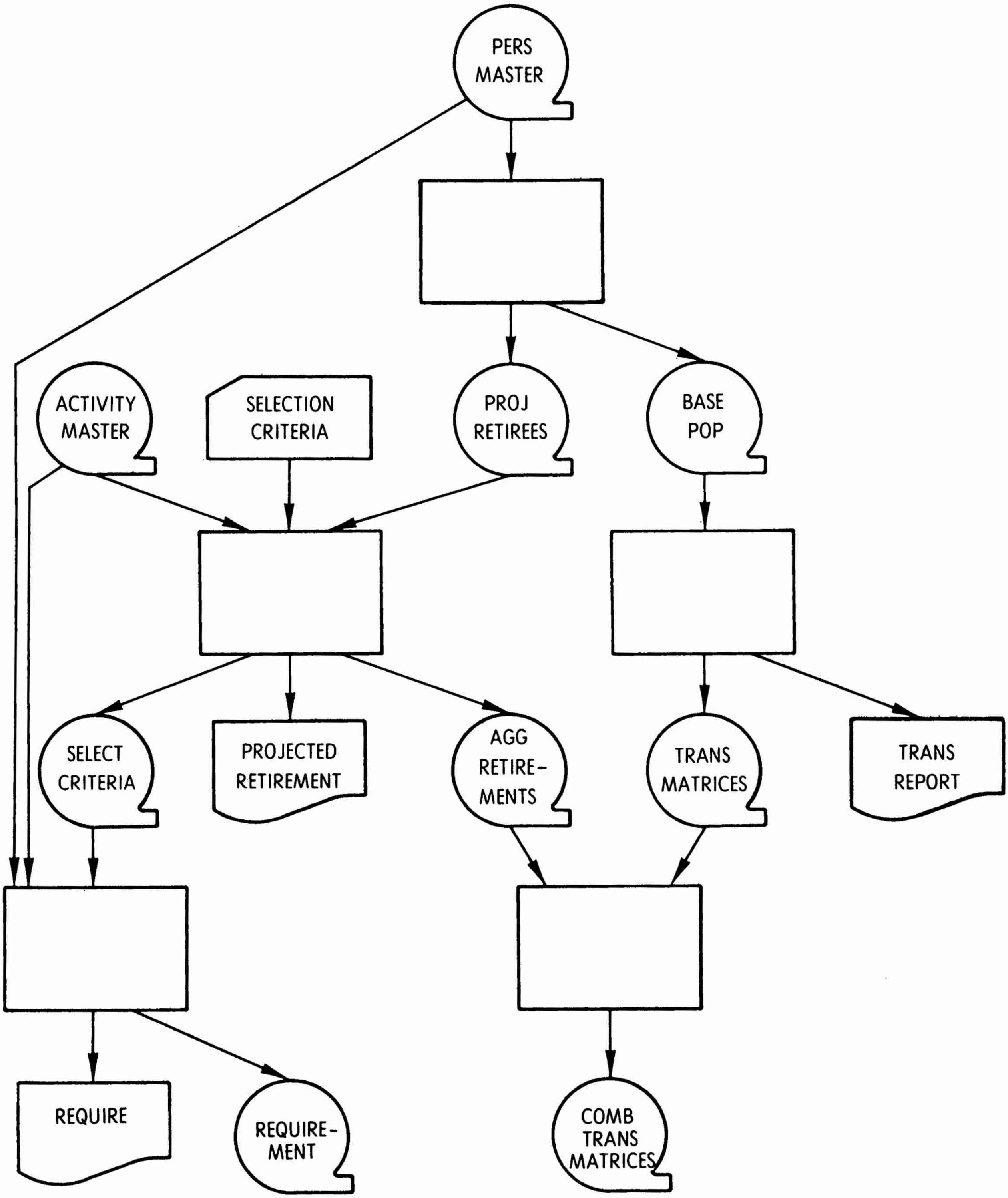

Figure 3

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COMPUTER ASSISTED MANPOWER ANALYSES SYSTEM (CAMAS)

TRANSITION RATE REPORT

RELATIVE FREQUENCY OF MOVEMENT INTER-STATE
FROM JUN 72 TO JUN 73

NON-RET ELIG IN ACTIVITY À SAN DIEGO

SEX MINORITY BIRTHDATE MC  ND  PROG EL  APPR CD   SNDL OCC GRP GRADE/LEV
BOTH                   ALL ALL  ALL             9999998  ALL       ALL

OF THE    64 EMPLOYEES AT JUN 72 IN STATE 80  1:
     42 OR 65.6% STAYED IN 80  1                   20 OR  31.2% WENT TO 80  3
                                                    2 OR   3.1% LEFT THE NAVY.

OF THE    78 EMPLOYEES AT JUN 72 IN STATE 80  2:
     58 OR 74.3% STAYED IN 80  2                    2 OR   2.5% WENT TO 80  3
      3 OR  3.8% STAYED IN THE NAVY BUT LEFT THIS POPULATION
                                                   15 OR  19.2% LEFT THE NAVY.
```

Figure 4

COMPUTER ASSISTED MANPOWER ANALYSES SYSTEM (CAMAS)

EXPECTED RETIREMENTS REPORT

EXPECTED RETIREMENTS FOR FISCAL YEAR 1977

ACTIVITY A SAN DIEGO CAL

OCCUPATION CLASS	APPRENTS	SEMISKIL	JRNEYMEN	LEADERS	SUPERS	TOTAL
ELECTRONIC MECHS	0	0	12	1	4	17
ELECTRICIANS	0	7	9	2	2	20
MACHINE TOOL OPS	0	2	15	1	1	19
METAL PROC WORKERS	0	4	4	0	1	9
METAL WORKERS	0	11	24	4	5	44
AIRCRAFT WORKERS	0	15	52	13	9	89
PIPEFITTING WRKRS	0	0	0	0	0	0
WOODWORKERS	0	1	1	0	0	2

Figure 5

the gross personnel requirements for future periods by job-types; again, the selection criteria allow the user to specify whether he is interested in the Navy as a whole, or in some subset such as activity, geographical area, etc. Once more, a report is produced; and the capability is provided here, as with the transition matrices, to alter any of the figures if the user feels that such changes are desirable in light of knowledge he may have. The gross requirements report may be seen in Figure 6.

USE OF FMPS

We have, then, two of the inputs to the LP problem; the others can be read in from cards. Our LP subsystem is schematized in Figure 7. We realize that UNIVAC's GAMMA 3 is available for use as an LP matrix generator, but we built our own -- for two reasons. To begin with, at the time we began work on our matrix generator we were not using UNIVAC equipment. But quite apart from that, we now have a generator that is specifically tailored to our needs, that affords us all the generality we need, and most importantly -- being written in ANSI COBOL and using SHARE LP format -- it is easily transferable from one machine to another. Operating, as we do, in Washington, where there are computers of almost every description available, we have already run our LP problems on Honeywell, GE, CDC, and IBM as well as UNIVAC computers; this flexibility is far more important to us than speed of originally writing the generator.

So far as the LP processor itself is concerned, we have just shifted to FMPS Level 5.0, after having used Level 8.2 for some time. Our problems have ranged in size up to 3,000 rows and 4,000 columns, which takes about 45 CPU minutes to solve. The only FMPS operating mode we have used is LP.

COMPUTER ASSISTED MANPOWER ANALYSES SYSTEM (CAMAS)

GROSS REQUIREMENTS REPORT

GROSS REQUIREMENTS FOR FISCAL YEAR 1977

ACTIVITY A SAN DIEGO CAL

OCCUPATION CLASS	APPRENTS	SEMISKIL	JRNEYMEN	LEADERS	SUPERS	TOTAL
ELECTRONIC MECHS	63	94	394	20	51	622
ELECTRICIANS	30	538	285	30	32	915
MACHINE TOOL OPS	31	88	260	7	25	411
METAL PROC WORKERS	0	80	73	0	11	164
METAL WORKERS	17	481	392	42	35	967
AIRCRAFT WORKERS	37	444	624	148	96	1,349
PIPEFITTING WRKRS	0	0	11	1	0	12
WOODWORKERS	0	22	12	0	3	37

Figure 6

COMPUTER ASSISTED MANPOWER ANALYSES SYSTEM (CAMAS) LINEAR PROGRAMMING SUBSYSTEM

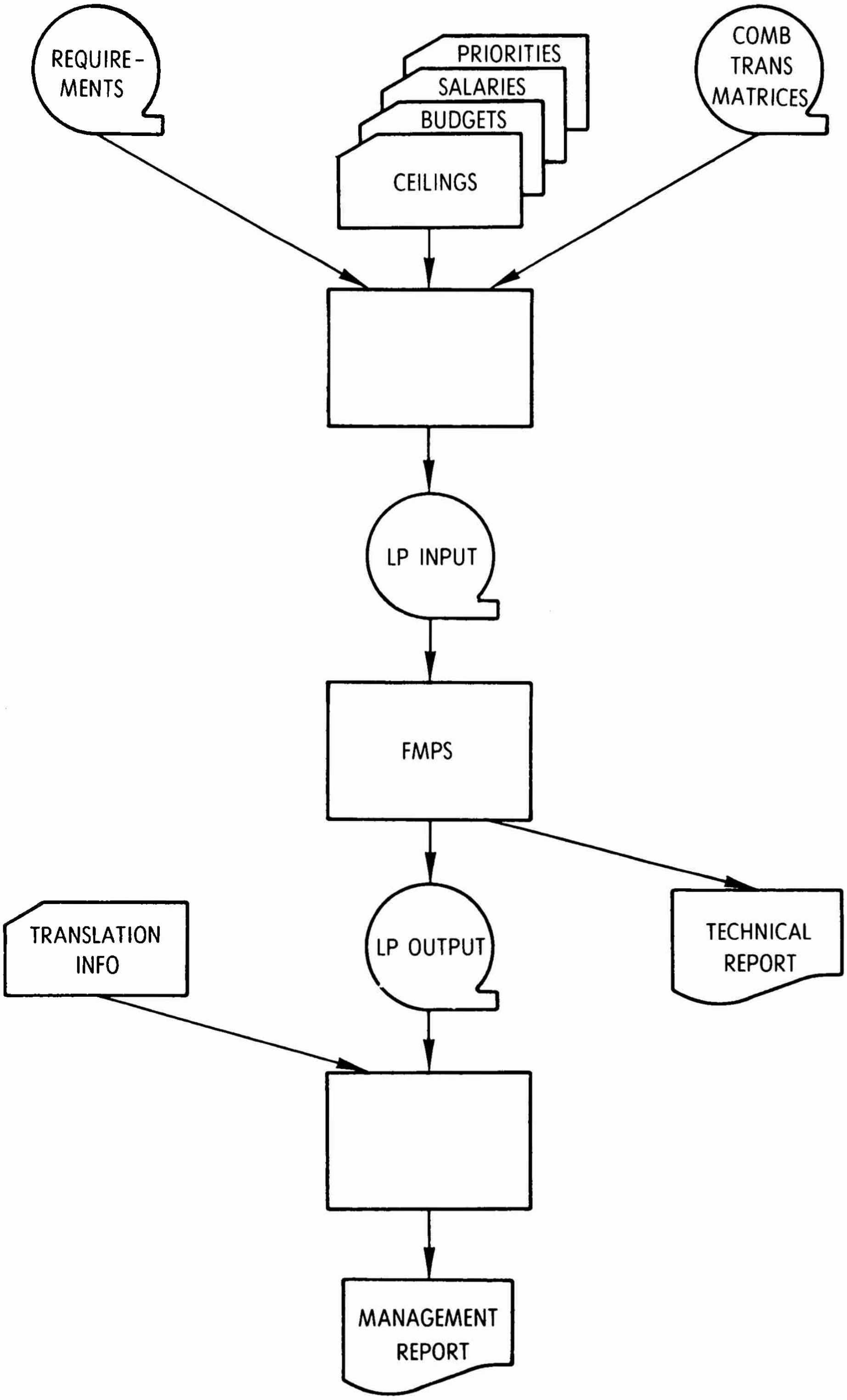

Figure 7

As with the matrix generator, we have preferred to write our own report-writer rather than use GAMMA 3. For the basic model we have already described, there are two output formats; a summary, and a detailed manpower report. Samples are given in Figures 8 and 9.

In the Summary there is one line for each occupational specialty and level. Given are the on-board figure at the beginning time, and then for each period of the forecast the number that would be aboard if the recommendations of the model were followed, the number of employees to be hired, and the number to be fired. The more detailed Manpower Report has for each period one line for each occupational specialty and level, giving besides the on-board figure and the numbers of hires and fires, the goal, the discrepancy from the goal, and the upper and lower limits.

APPLICATIONS AND MODIFICATIONS

You have now seen our basic model and the computer system we have built to support it. It was not long after we first had this model working that we were called upon to make our first modification -- which we usually refer to as the average-grade model. You may remember that in the autumn of 1971, the Office of Management and Budget recommended that the average grade of the government's white collar workers be reduced by a fixed amount over the next two years. Also, the Department of Defense was scheduled for sizeable reductions during that period. However, because of existing Civil Service regulations, average grade generally increases during periods of reduction.

COMPUTER ASSISTED MANPOWER ANALYSES SYSTEM (CAMAS)

SUMMARY MANPOWER REPORT

ACTIVITY A SAN DIEGO CAL

CATEGORY	CODE	ABOARD 1973	1974 ABOARD	1974 HIRES	1974 FIRES	1975 ABOARD	1975 HIRES	1975 FIRES
ELEC MECH 1	1011	55	57	15		63	20	
ELEC MECH 2	1012	81	85	18		94	24	
ELEC MECH 3	1013	341	355	41		394	67	
ELEC MECH 4	1014	17	18	5		20	6	
ELEC MECH 5	1015	44	46	2		51	5	
ELECTRIC 1	1021	26	27	13		30	15	
ELECTRIC 2	1022	466	484	102		538	143	
ELECTRIC 3	1023	246	256	37		285	57	

Figure 8

COMPUTER ASSISTED MANPOWER ANALYSES SYSTEM (CAMAS)

DETAILED MANPOWER REPORT

ACTIVITY A SAN DIEGO CAL

MANPOWER REPORT FOR 1977

CODE	CATEGORY	ABOARD	HIRES	FIRES	GOAL	DISCREP	LIMITS	
1021	ELECTRIC 1	30	14		30		27	33
1022	ELECTRIC 2	538	102		538		484	592
1023	ELECTRIC 3	285	35		285		257	313
1024	ELECTRIC 4	31			30	1	27	33
1025	ELECTRIC 5	32		5	32		29	35
1031	MACH TOOL 1	31	11		31		28	34
1032	MACH TOOL 2	88	19		88		79	97
1033	MACH TOOL 3	260	19		260		234	286

Figure 9

The Navy Department, among other agencies, was then in the position of being constrained to follow a very difficult set of policies. Since OCMM is the organization which allocates ceilings to the Navy's activities, it was our office which had to deal with the problem. We made just a slight modification to our model to add another set of rows, saying that for each period the total number of grade-points had to be less than a given limit; and then, to prevent the model from simply cutting the on-board figures, we set the ceiling constraints to equalities.

The LP matrix then appeared as in Figure 10. With this model we were able to prove that it was impossible for the Navy to meet its average grade constraint without causing a drastic imbalance in the composition of the workforce. As a result, Navy received partial relief from the requirement. Thus, management was able to use the model in testing an imposed policy on the civilian workforce of the entire Navy.4/

The model has also been used at the all-Navy level to look at the effect of various kinds of reductions in the work force. Here the power of such a computerized model is shown off to best advantage, for not only can the model show what kind of occupational balance can be maintained and how many and what kinds of workers would have to be fired under each proposed reduction plan, it can also be used to test the effect of various policies to determine to what extent they would be helpful in each plan. Thus, such policies as freezes on hiring, total or partial, or freezes on promotions, or reducing the rates of promotion, either overall or in selected categories, can be tested and their relative values assessed <u>before</u> any policies are promulgated.

4/ See Chapter IV of [4], [6], and [7].

ABOARD Base	ABOARD Projected		HIRES	FIRES	EXCESSES		DEFICIENCIES		RHS
1									= Init. Pop.
	1				-1		1		= Goals
		1				-1		1	
-M	1		-1	1					= 0
	-M	1	-1	1					
	1...1								= Ceilings
		1...1							
	1,2...18								≤ Grade Pts
		1,2...18							
	sal...sal								≤ Budgets
		sal...sal							
	1								≥ Lower Limits
		1							
	1								≤ Upper Limits
		1							
MINIMIZE			α	β	γ			δ	

AVERAGE GRADE MODEL

Figure 10

In a similar manner, these models can be and have been applied at an individual activity, or installation. Of course, if the activity is too small, rounding errors will destroy whatever value the model might have. But for a sufficiently large activity, these models can be very useful in determining the effects of changing constraints imposed from without and of various policies being considered by management. The Naval Underwater Systems Center (NUSC) in Newport, Rhode Island, is a good example.5/

Another modification of the model was made to allow us to look at several subparts of an organization, or alternatively, at collections of activities; thus, we refer to it as the multi-activity linked model. Here we have essentially a basic model for each of the sub-organizations, which we will call producers, with a new set of rows requiring all of the sub-elements to be constrained by a common ceiling in each period. The model then appears as in Figure 11. Because of the increased size of diagram required by multiple producers as well as multiple time-periods, we have switched to a more summarized type of representation. This version of the model has been used to look at program areas of a large activity, as well as looking collectively at the activities comprising a major command,6/ one of the organizational entities into which the Navy is divided.

The most complex extension of the model we have undertaken to date is called the recruiting requirements model with Input-Output relationships, or the multi-level model, or sometimes the support-on-support model. Here we are interested in looking at sub-parts of the organization not as

5/ See [5]
6/ See [6]

TO MINIMIZE: α(HIRES) + β(FIRES) + γ(EXCESSES) + δ(DEFICIENCIES)

SUBJECT TO:

Numbers ABOARD in base period for each producer	=	INITIAL POP.
Numbers ABOARD for each period and producer - EXCESSES + DEFICIENCIES	=	MANP. GOALS
Numbers REMAINING from last period + Numbers ABOARD - HIRES + FIRES	=	0
Sum for each producer and period of numbers ABOARD	$\leq$	CEILINGS
Sum for each period of numbers ABOARD	$\leq$	COMBINED CEIL.
Sum for each producer and period of (Numbers ABOARD x salaries)	$\leq$	BUDGETS
Numbers ABOARD for each period and producer	$\geq$	LOWER LIMITS
Numbers ABOARD for each period and producer	$\leq$	UPPER LIMITS

MULTI-ACTIVITY LINKED MODEL

Figure 11

tied together by a common ceiling, but rather as interacting among each other to provide support. In this case the driving force is not simply the attempt to meet the manpower goals as closely as possible, but also includes trying to meet final user requirements as nearly as possible.[7/]

A hypothetical working example of this multi-level or support-on-support model has been built, and the initial supporting software tested. A considerable amount of research remains to be done, however, prior to the application of this model to large-scale problems.

CURRENT RESEARCH

You have seen the structure of the model we built and some of its applications and extensions. We might talk a bit now about the research we have currently in progress. The supporting computer system now used is a batch system. Even after the initial data is gathered and processed, it still takes approximately a day for each run of an alternative. Also, a technician is required to decide how to make desired data changes and to resubmit the job. This not only makes the model somewhat less useful in situations in which immediate decisions are required, but also militates against its wider acceptance by management. Therefore, we are now involved in experimenting with the conversational use of our models, whereby a manager himself, if he wishes, may sit down at a CRT, and after a short explanation involving only terms with which he is completely familiar, be able to do repeated runs testing alternative sets of conditions or policies.[8/]

7/ See [2] for discussion of a possible application.
8/ See [9] for a discussion of this conversational model.

The second area in which we are currently doing research is that of working on an advanced start for the LP process. Even in the batch mode, but more particularly in the conversational mode, speed of optimization is of crucial importance. Joint work with Carnegie-Mellon University in Pittsburgh and the University of Texas at Austin has resulted in an algorithm for directly and quickly finding a feasible solution near the optimum.[9/] Programming will be initiated shortly, so that we can test it with operational size problems. If this method proves to be of practical value, it will give us a powerful advantage in using FMPS.

9/ See [1] for a discussion of this advanced start algorithm. It should be noted that its use appears not only to be applicable to manpower planning but more generally to problems of the convex goal programming variety.

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